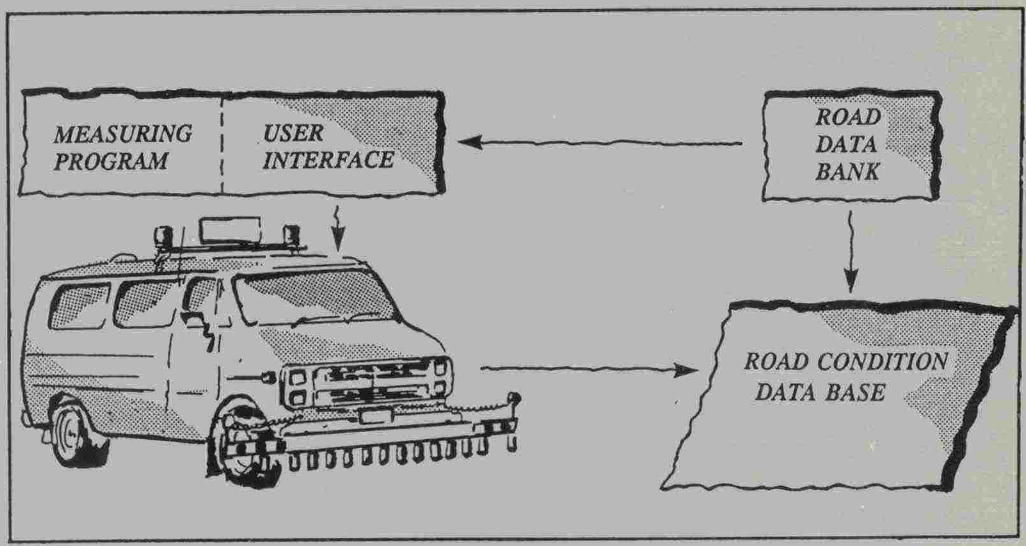
Taina Rantanen

Road Condition Measurements and Pavement Management in Finland



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SUMMARY

The road structure is designed to distribute different kind of sresses to the subsoil in a way permanent deformations on the subsoil can be avoided/minimized. The role of maintenance is to take care the structure meets this goal.

There are things that effect on the service level of the road although there might not be any structural problems - and via versa. If the maintenance is planned only in a point of view of serviceability and the structural problems are ignored it may be very expensive to maintain the road in a long run. on the other hand it is uneconomic to have the road in a better condition that is required.

It is an overwhelming task to take all these aspects on all roads into consideration and at a same time predict the future condition and how the maintenance actions affect the change in it. It's a challenge for a knowledge-based expert system to show its best properties: objectivity, top memory and logical procedures.

The Finnish National Road Administration (FinnRA) has developed this kind of expert system: a Pavement Management System covering maintenance procedure from strategic planning to programming of repaving. It has also developed tools for measuring and recording the essential condition data for these systems.

This manual describes what kind of input data PMS needs and how it is measured. It also describes the different parts of the PMS and how these parts use the data and how the system supports decision makers.

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I PAVEMENT CONDITION STATE INDICATORS

The description of existing pavement performance consists of four different type of variables: ruts, evenness, defects and bearing capacity. Each of these variables can be measured and expressed in many different ways. Ruts, evenness and defects tell illustratively how the pavement looks like, on the other hand they may be intepreted as symptoms of structural problems. Especially defects tell about frost action and loss in bearing capacity.

The table below shows how the different condition state indicators influence the road user - on the other hand- and the maintainer on the other. Both the user's and the maintainer's point of view should be taken into consideration when planning maintenance strategy.

Table 1. Condition state indicators and their influence on road user and maintainer.

PROBLEM	USER	MAINTAINER
RUTS	* change in traffic safety * reduced riding comfort * increase in costs (time)	* waterlayer ⇄ wearing * problems in winter maintenance
ROUGHNESS	* reduced riding comfort * increase in costs (vehicle, fuel)	* increased dynamic loads to road structure
DEFECTS	* careless overall impression * reduced riding comfort on uttermost cases	* water leakage more defects reduced bearing capacity
BEARING CAPACITY	-	* increased deterioration rate

Ruts

Measuring devices

Ruts are measured by a specific vehicle called RSM (Road Surface Monitoring, figure 1). The vehicle is a part of the total system including also data processing software.

Ruts are measured at the speed of traffic (40-90 km/h) by 15 ultrasonic distance sensors attached in the front bumper of the RSM-car. They measure the distance between road surface and detector level. It is possible to get immediate reports for checking the data during measurements.

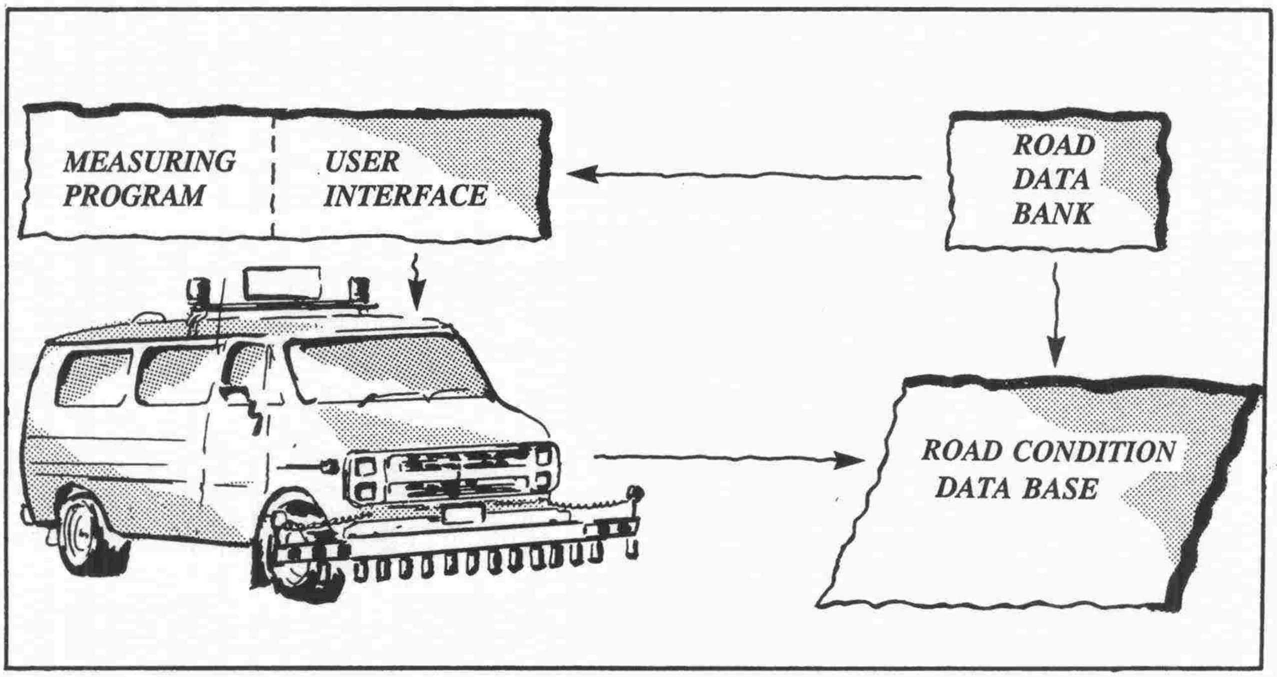


Figure 1. Ruts are measured by RSM-car.

Measured values

The roads with high volume are measured every year. Transverse profile is measured at 2 m intervals then calculated in sections of 10 and 100 m, see figure 2.

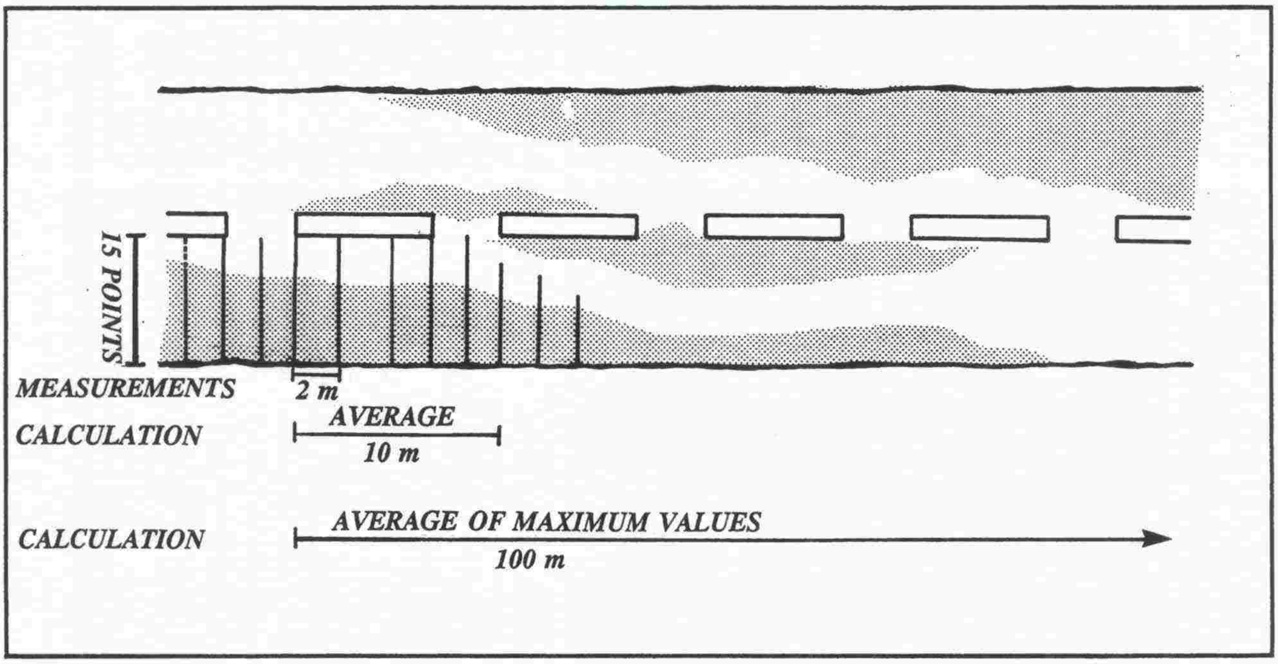
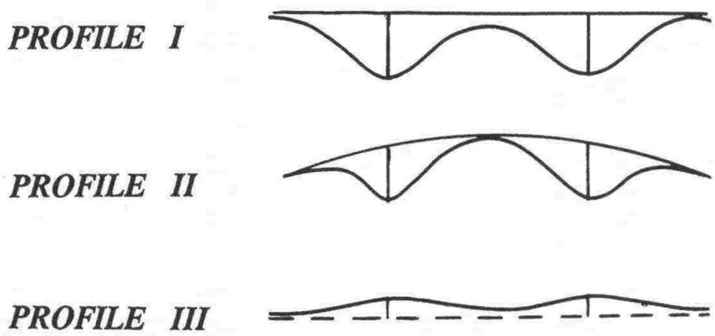


Figure 2. The principle of processing rut depth values.

The measurements produce following data:

* average rut depth, the determination is demonstrated in figure 2
* the amount of different rut profiles per hundred meter



* maximum value of rut depth per hundred meter
* the cross-sectional area of the rutted profile
* average and variance for both edge and center rut

Characteristic values and their use, prediction model

Average of the maximum rut depth values is the characteristic value utilized in the pavement management system. There is a linear prediction model for increase of rut depth, see figure 3. It's based on the measured values and the age of the pavement.

RUT DEPTH = RUTTING RATE * TIME (Y) + PREDEFORMATION
RUTTING RATE = (MEASURED VALUE - PREDEFORM.)/PAVEMENT AGE
CHECK FOR MINIMUM AND MAXIMUM VALUES

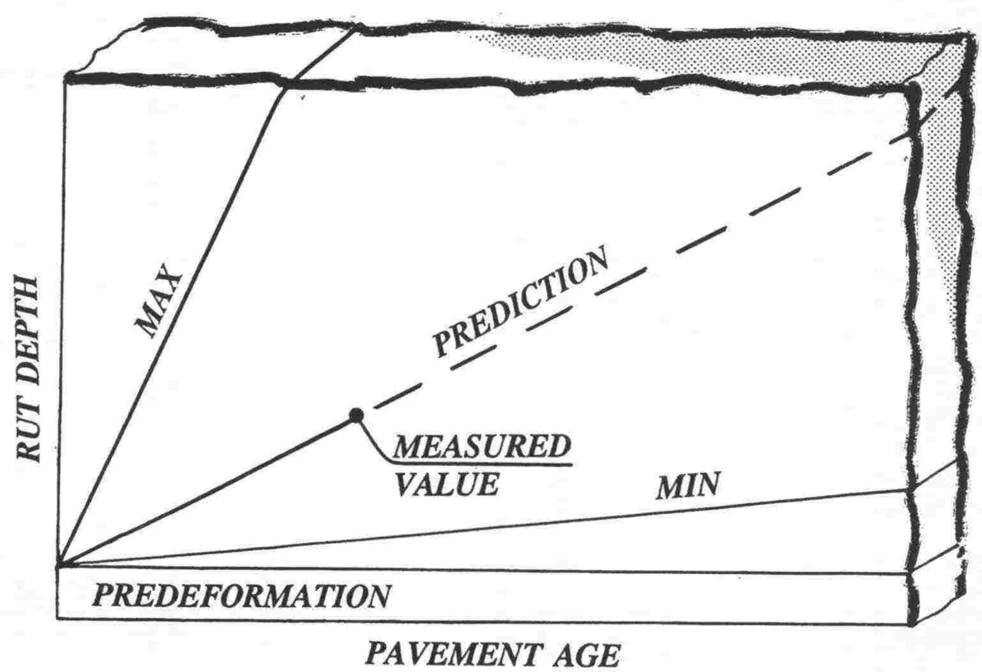


Figure 3. Model for predicting the increase of rut depth.

Evenness

Measuring device

Evenness is measured at the same time with the rut measurement by RSM-car, see figure 1. Laser sensor is attached in the front bumper of the RSM-car to measure the distance between car body and pavement surface. Accelerometer gives further information about bumps and settlements.

Measured values

Measurements are made every second year on same road sections. The distance between car body and pavement surface is measured every 4 cm and then produced into IRI-value, see figure 4.

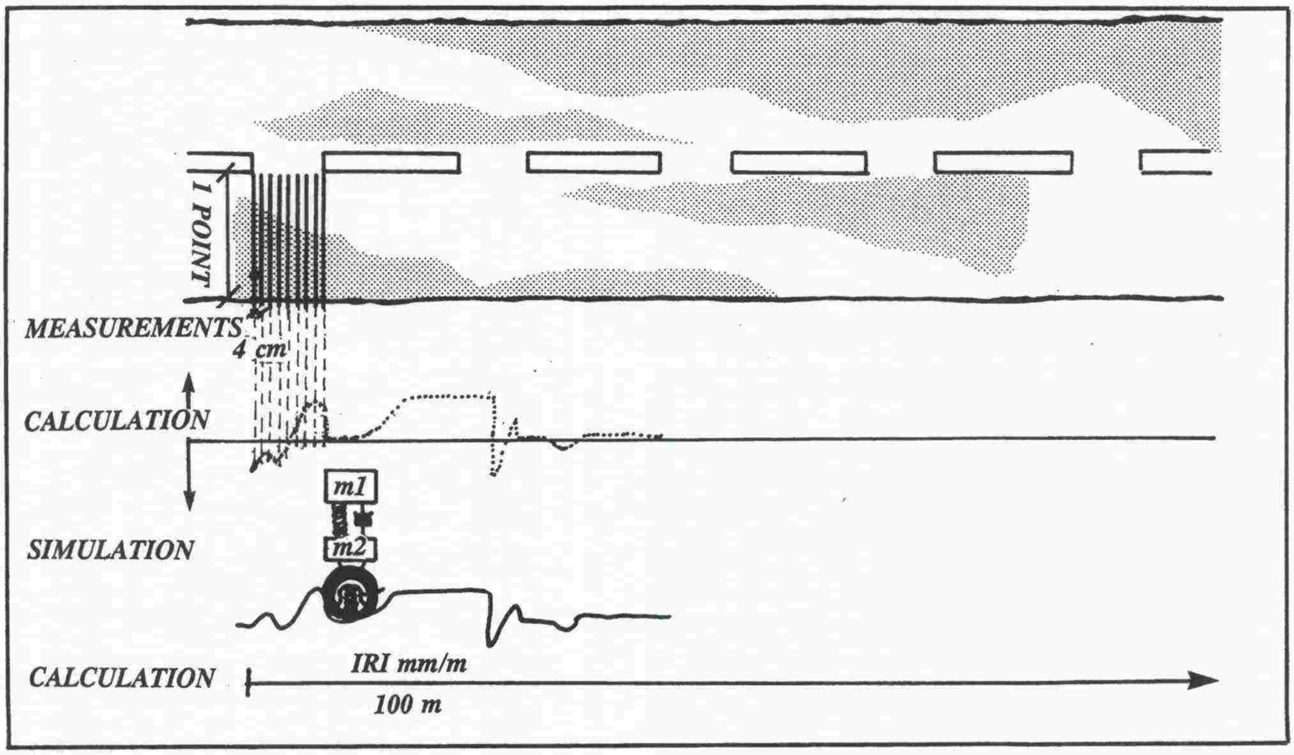


Figure 4. The principle of determing IRI-value.

Following values are produced during the evenness measurement:

* IRI mm/m per hundred meter
* count of bumps classified in eight different classes according to acceleration value and wavelength
* maximum vertical acceleration value (m/s^2) and its position
* IRI-4-index, unevennesses with vawelength more than four meters are filtered
* DFI, the Dynamic Fatigue Index

Characteristic values and their use, prediction model

IRI is the main value used in analyzing the longitudinal profile of a road surface. In PMS there is a prediction model for the change of IRI.

EVENNESS = K * PREVIOUS VALUE + A

PREVIOUS VALUE =
1) MEASURED OR DEFAULT VALUE (FIRST YEAR)
2) PREDICTED VALUE (FOLLOWING YEARS)

K, A VARIABLES, DEFAULT VALUES K = 1,03, A = 0,13

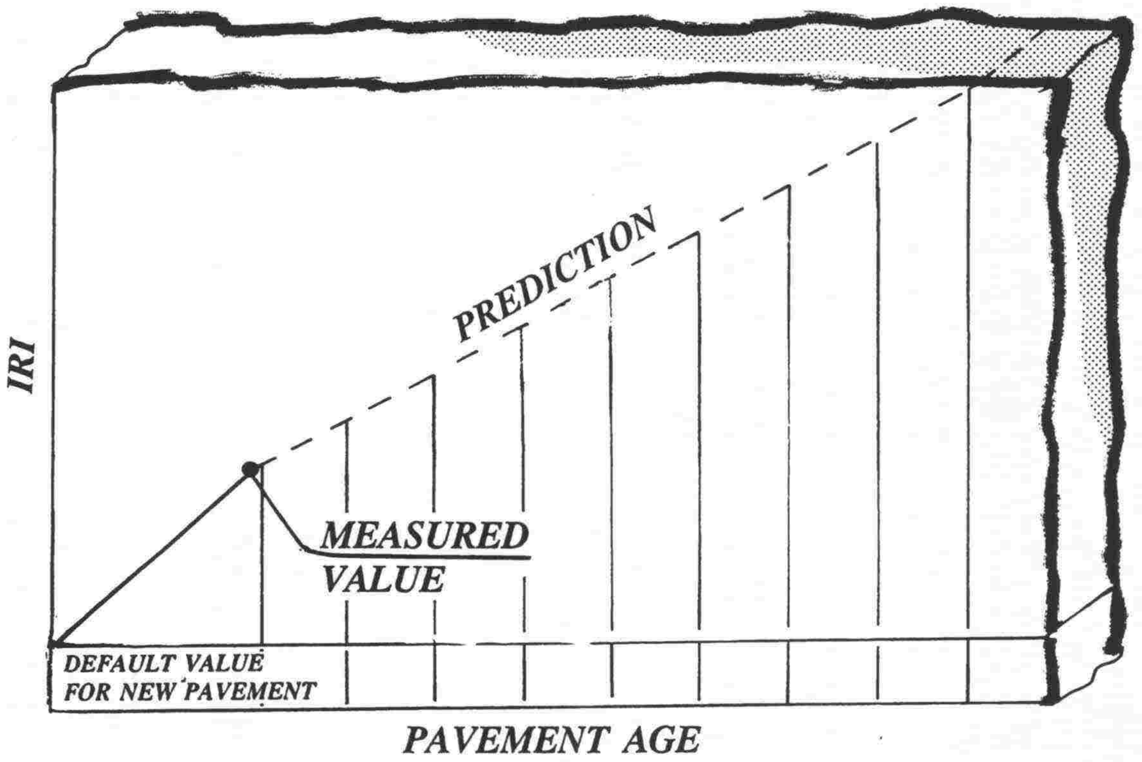


Figure 5. Prediction model for the change of IRI.

There are also numerical classifications and verbal discriptions telling about riding comfort. For example IRI-index below 1.3 mm/m describes a very good road and IRI-index over 5.6 means, that driving becomes very uncomfortable. Bumps having acceleration value less than 2.0 m/s^2 are considered minor, values over 3.5 m/s^2 are considered major.

IRI is also used for evaluating if the evenness of new pavement fulfils the given standards.

The importance of DFI (Dynamic Fatigue Index) is acknowledged and there is a project to define the characteristic values to be used in PMS.

Defects

Measuring device

Defects are measured visually from a car or a van at a very low speed (3-4 km/h).
The measurements take place in spring (april-may) in the beginning of thaw period. During measurements the pavement should be free of snow and ice.

Defects are recorded on certain formulas or on a specially developed digital board, see figure 6. The measurements need two persons: the driver evaluates the type and amount of defects visually while the other member of the measurement unit codes defects. Mileometer is used in both locating the measurement sections within road sections and in evaluating the length of the cracks. All defects on a certain road section are combined on 100 meter level and transformed into the dataprocessing system PVI.

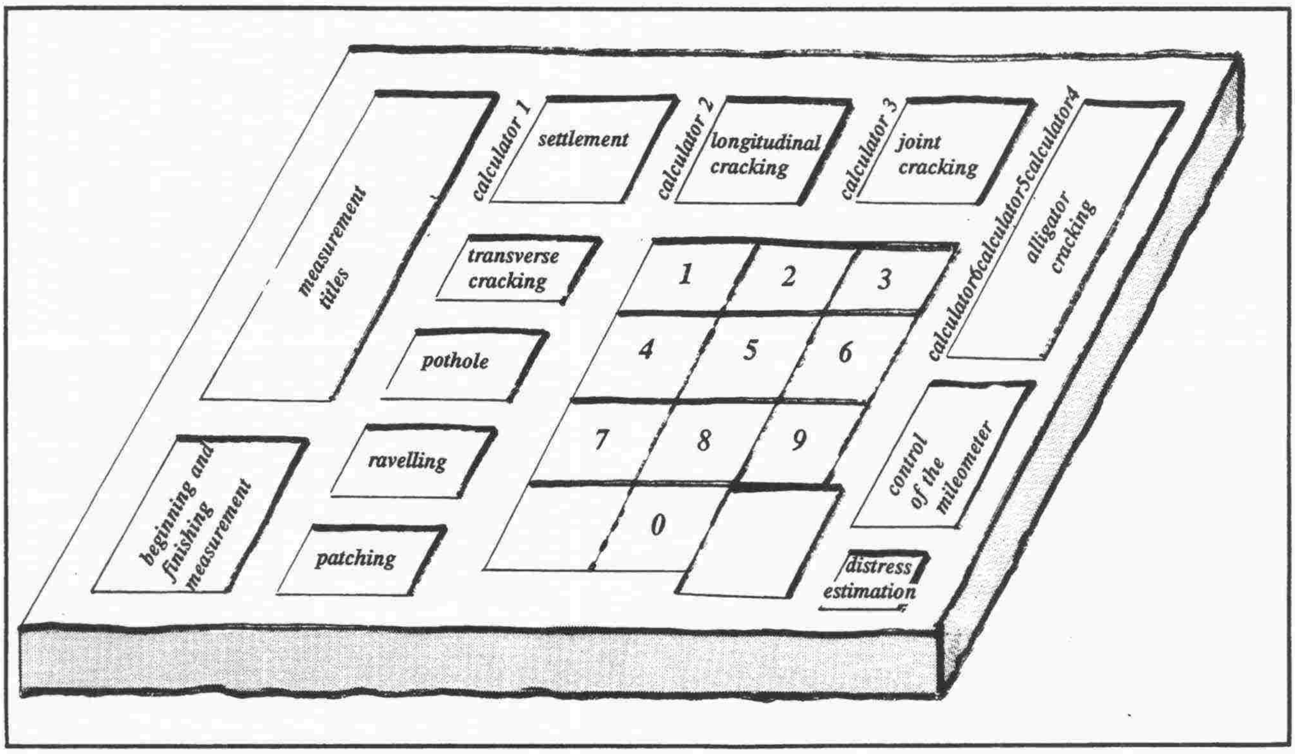


Figure 6. Digital board for recording pavement defects.

Measured values

Defects are measured every third year on same road sections. The first inventory on new pavement isn't necessary earlier than in the third or fourth year from paving. Eight different type of defects are measured as shown in figure 7 and listed in table 2.

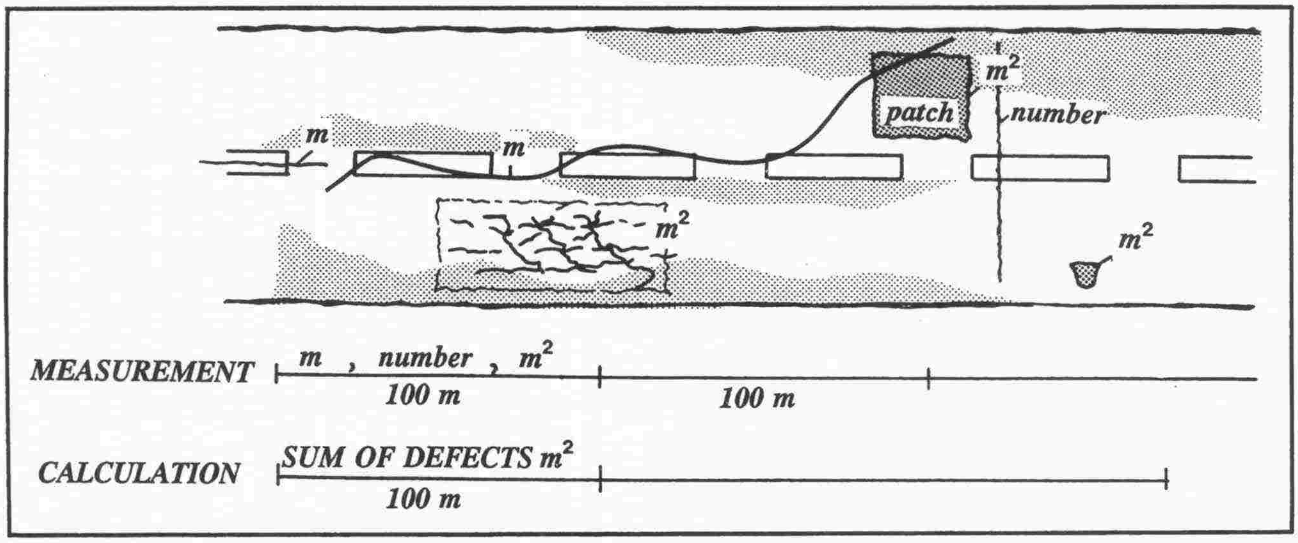


Figure 7. Defect measurements in 100 meter sections.

Table 2. Description of defects.

Type of defect	Description	Measuring
Transversal cracks	Caused by stresses due to cold temperature, faults in mass or work, frost heaves	In numbers, only the cracks with length over 2 m
Longitudinal cracks	Mainly caused by uneven frost heave or settlements; parallel or at an angle to roadline	In meters
Joint cracks	Caused by frost heaves or faults in joints; longitudinal or transversal cracks in the joint of two pavement layers, usually in the middle of the road	In meters
Alligator cracking	Polygonal cracking caused by loss in bearing capacity or aging of pavement	In square meters
Potholes	Caused by segregation/ravelling procedure, gets worse along with frost-thaw-cycles	In square meters, always at least 1 m^2
Ravelling	Caused by segregation in pavement mixture, some aggregates have already been detached, will change into a pothole along with time	In square meters, always at least 1 m^2
Patches	Small patches classified as first aid, those considered as proper rehabilitation actions are not recorded	In square meters, always at least 1 m^2
Settlements	Longitudinal settlements on the edge of the road; on narrow roads caused by loss in bearing capacity	In square meters, always at least 1 m^2; recorded only if some levelling is needed before paving

Characteristic values and their use, prediction model

The inventoring of all the detailed defect data gives exact information how the pavement looks. The combined effect of different type of defects is calculated by multiplying individual cracks with weighted factors and then summarizing them. The result is called sum of defects. It describes the area of damaged pavement.

Table 3. Weighted factors for calculating the sum of defects.

Type of defect	Measured in	Weighted factor
Alligator cracking	m^2	1,0
Longitudinal cracking	m	0,5
Transverse cracking	number, default length 4 m	0,1
Joint cracking	m	0,1
Potholes	m^2	1,0
Patches	m^2	1,0

Objective information is available equally for the whole road network.Classifications and threshold values for repaving, reconstruction etc. are given in exact numbers using both the sum of defects and the amount of individual defects. There is a model for predicting the change of the sum of defects, the increase of individual cracks doesn't have any model.

SUM OF DEFECTS = RATE * TIME^N

RATE = (MEASURED VALUE)/(PAVEMENT $\text{AGE})^N$

N = VARIABLE, DEFAULT VALUE FOR ASPHALT CONCRETE IS 1.6

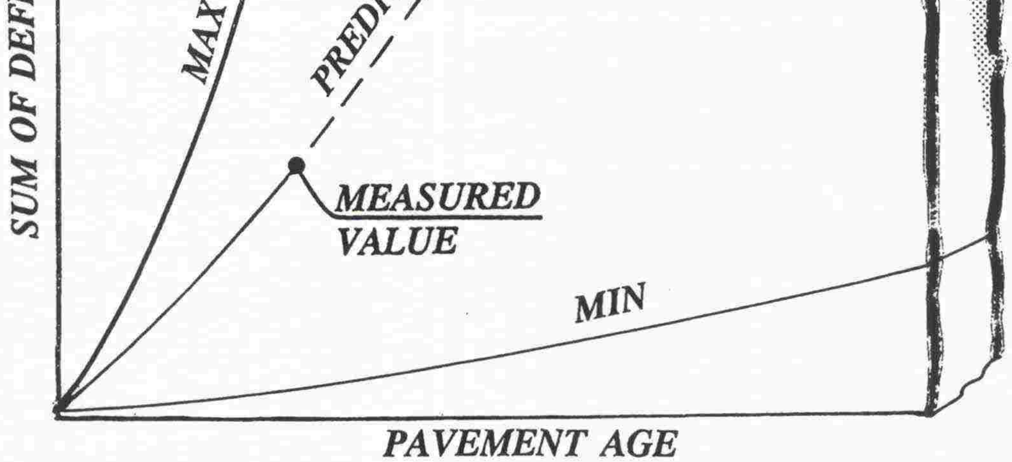


Figure 8. The prediction model for the change of the sum of defects.

Bearing capacity

Measuring device

Falling weight deflectometer is the main method in measuring bearing capasity (figure 9). Road structure is loaded with a falling weight and deflections caused by the load are measured in different distances from the loading point.

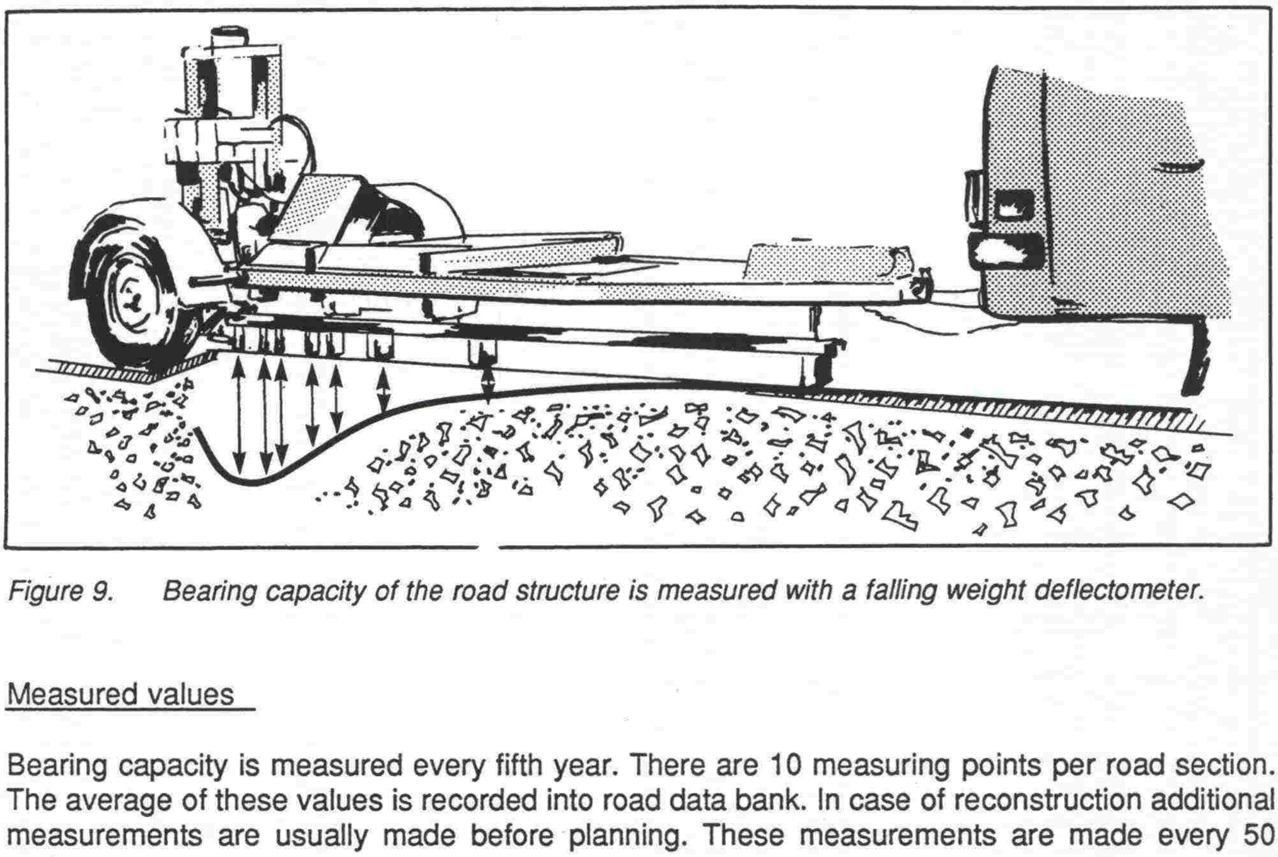


Figure 9. Bearing capacity of the road structure is measured with a falling weight deflectometer.

Measured values

Bearing capacity is measured every fifth year. There are 10 measuring points per road section. The average of these values is recorded into road data bank. In case of reconstruction additional measurements are usually made before planning. These measurements are made every 50 meters.

Measured deflections in different distances from the loading point are recorded and plotted to form the deflection curve (figure 10). In addition are recorded the temperature of the pavement layer and the air to give information in transforming the measured values into the bearing capacity of the road structure.

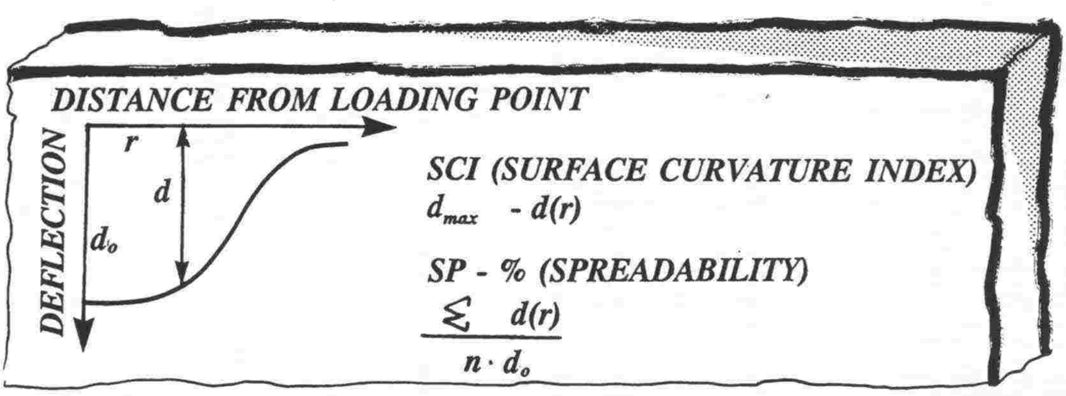


Figure 10. Deflection curve gives information of different structure layers.

Characteristic values and their use, prediction model

The mainly used value calculated from measurement data is the bearing capacity of the road structure. The shape of the deflection curve tells about the condition state of different structure layers and the bearing capacity of the subsoil (figure 10). Surface curvature index (SCI) is the difference between maximum deflection and deflection at certain distance from the loading point. SCI describes the tensile stresses in the lower surface of the pavement layer. Also the modulus of elasticity (MN/m^2) of different layers can be backcalculated from the deflection values.

There is no model for the decrease of bearing capacity. Instead the measured bearing capacity value is compared with the dimensioning value, which is calculated according to accumulated equivalent axle load, figure 11. If the ratio (measured/dimensioned) is less than 1.00 there is a loss in bearing capacity.

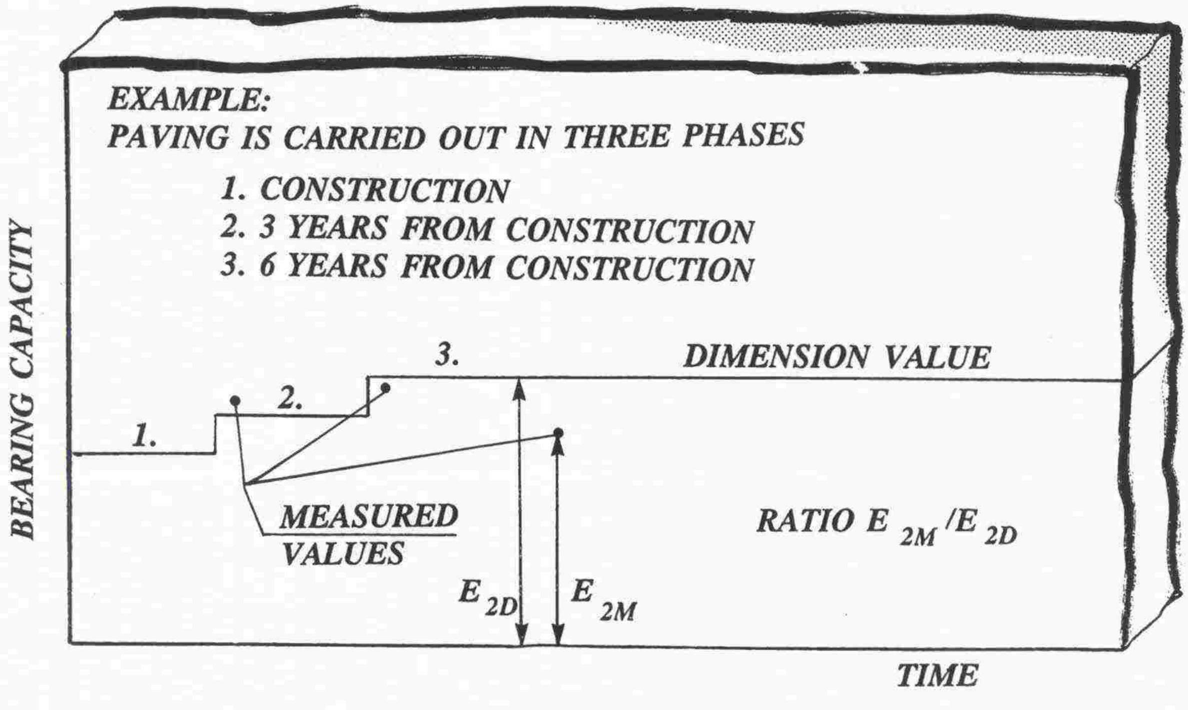


Figure 11. Comparing the measured bearing capacity with the dimensioned one.

In case of reconstruction the data given by falling weight deflectometer is analyzed together with defect data, frost damage evaluations, sample data of the structure layers, ground penetrating radar information etc to find the most suitable method for improving the structure.

Classification of Condition State Indicators

Finnish National Road Administration (FinnRa) has determined certain classifications for condition state indicators. These values are based on the results of a special experimental project. They are valid in 1993 but they may change along with experience and research work.

Table 4. Classification of pavement condition (average values per hundred meter).

CLASS VARIABLE	ROUGHNESS IRI mm/m	RUT DEPTH mm (speed limit 80 km/h)	SUM OF DEFECTS m^2
EXCELLENT	... 1.3		... 5
GOOD	1.4 ... 2.6	... 18	6 ... 20
FAIR	2.7 ... 4.1	19 ... 24	21 ... 40
POOR	4.2 ... 5.5	25 ...	41 ... 80
BAD	5.6 ...		81 ...

In addition the threshold values for measuring productivity are set annually. These values reflect the present condition state distribution and economical situation.

II PAVEMENT MANAGEMENT SYSTEM

Structure of The System

Pavement Management System gives tools for

* evaluating the present state of road network
* predicting the change in condition state
* setting goals for the future
* planning maintenance policy and actions according to this information.

PMS consists of two data banks: Road Data Bank RDB and condition data bank KURRE, and two expert-systems: the network level system HIPS and the project level tool PMS91. The systems for pavement condition measurements are described in chapture I.

All these systems are maintained and developed by the central administration, district offices are responsible for updating of data.

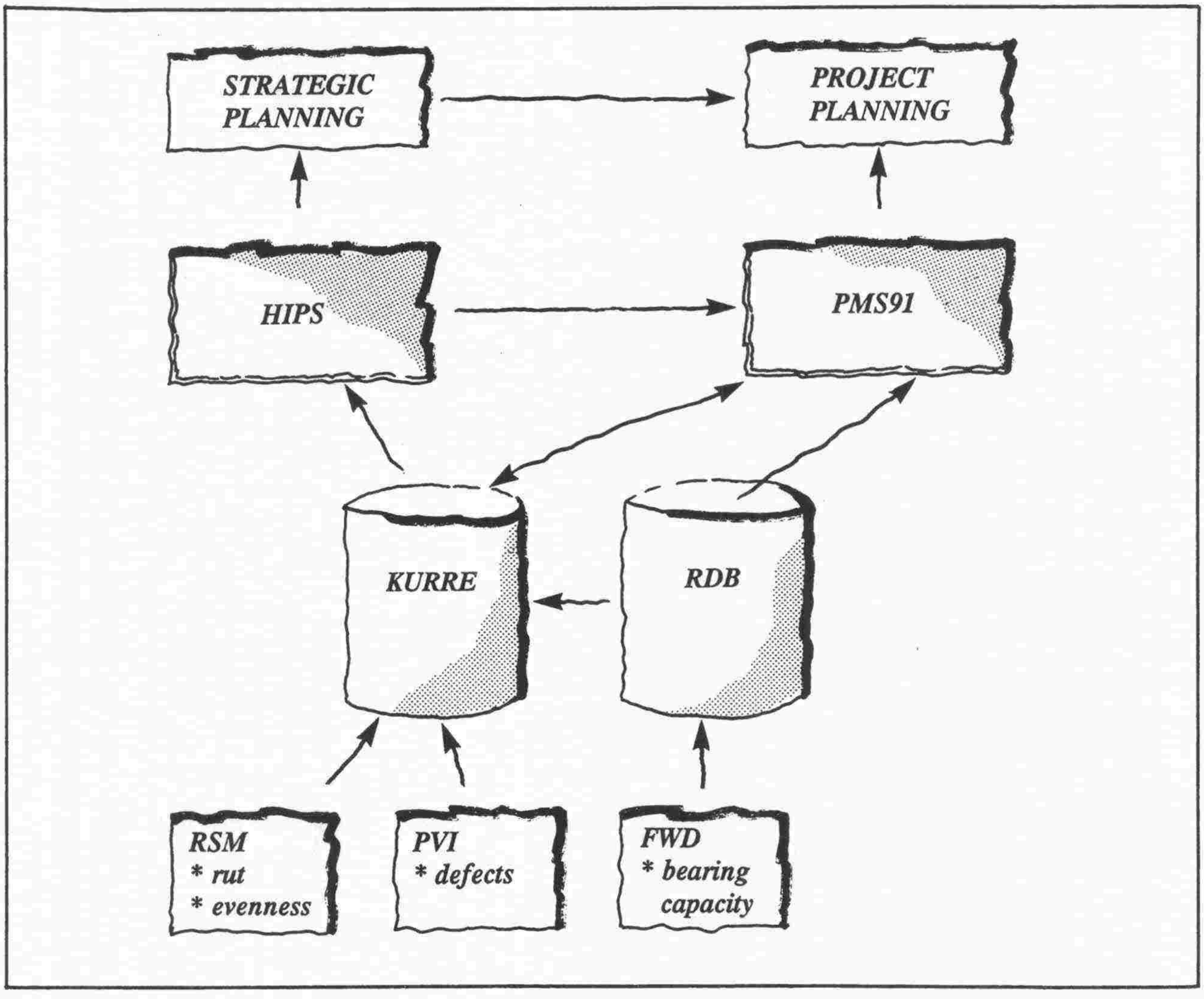


Figure 12. The parts of PMS.

Contents, Purpose and Technical Data of Different Parts

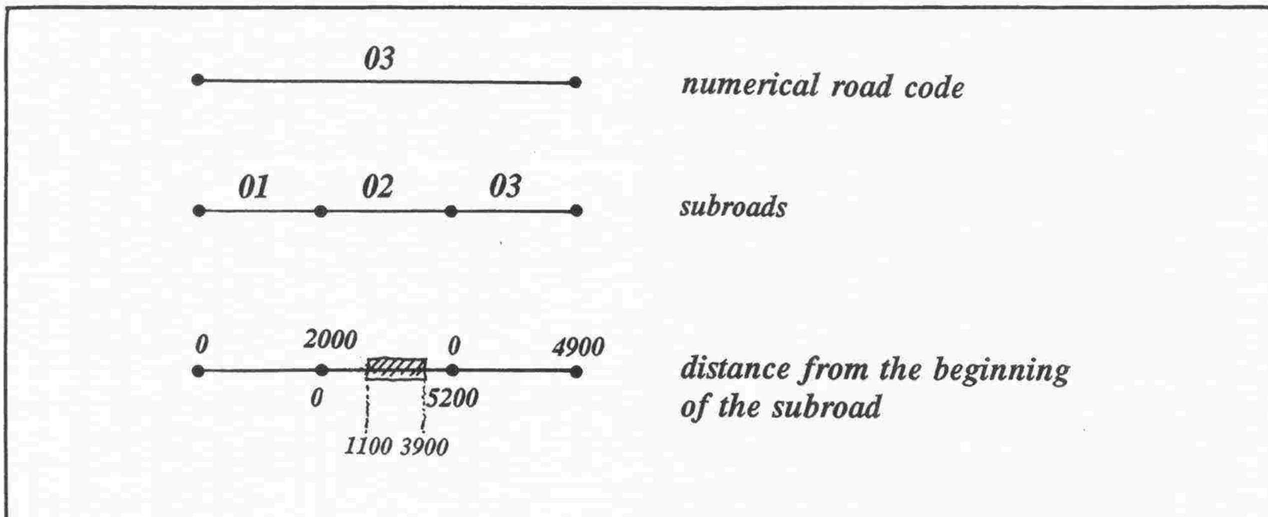
Table 5. Contents, purpose and technical data of the different parts of PMS.

RDB	KURRE	HIPS	PMS91
* road address reference system * basic data of roads and traffic * the data is given in codes	* detailed condition data: history, present, future	* prediction models * actions and effects * user and agency costs	* prediction models * decision rules * actions and effects
Administration * research * statistics **District** * input data for PMS91 and other planning systems * statistics	**Administration** * research * input data for HIPS * statistics: present and predicted condition state distribution * annual objective setting **District** * input data for PMS91 * statistics * data for planning reconstruction	**Administration** * strategic planning and goal setting * cost-effective maintenance policy **District** * input data for PMS91	**District** * recommendations for individual roads * programming of repaving * effect analysis
* CODASYL-database * in use since 1970's	* ORACLE-relational database * in use since 1991	* programming language C * in use since 1989	* PARADOX-relational database * programming language C * in use since 1987

Functions

<u>Road Data Bank RDB</u>

Road Data Bank contains basic data of roads and traffic and the system to locate all the data to a particular road segment (road address reference system, figure 13). The main data used in PMS is the information about pavement and traffic volume.



EXAMPLE: ROAD ADDRESS FOR THE SHADED ROAD SEGMENT
3 02 1100...3900

Figure 13. Road address reference system.

RDB produces also service files for planning of transportations, to road user infosystem, traffic volume forecasts, distance matrices, HCM (level of service) etc. It gives statistics about the extent of the public road network, which is annually produced in a form of map.

Because the accuracy of the data is essential there are special groups in the district offices to take care of the annual measurements.

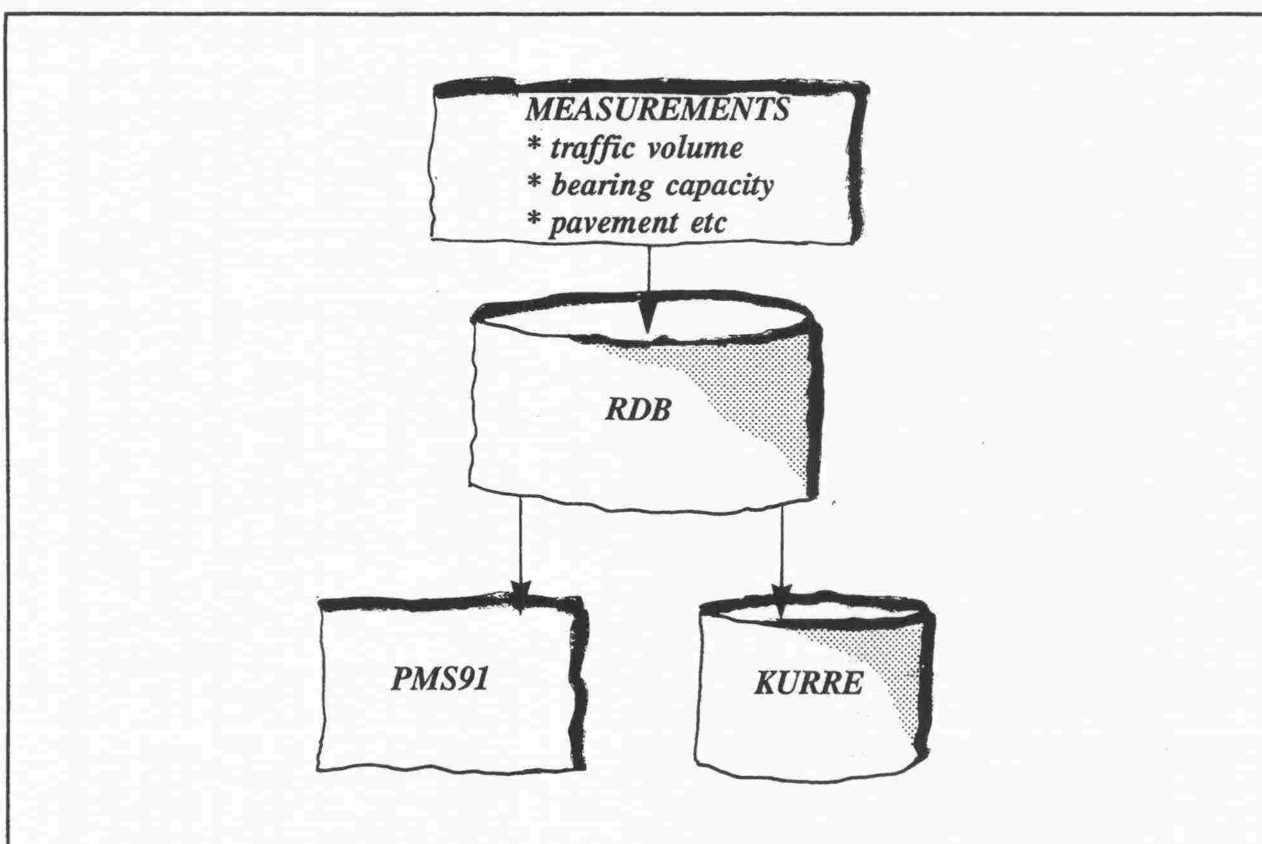


Figure 14. Road Data Bank as part of PMS.

Condition Data Bank KURRE

KURRE contains the history, the present and the future values of the condition state indicators for every 100 m:s section of the road network. It has the same models as in PMS91 for predictions. By using prediction models it is possible to get up-to-date condition state distributions although some measurements might have taken place 1-3 years ago.

One of KURREs functions is to check that the measurements will be referred to right places. If for example the number of a road has changed between two measurements the address of the measurements from previous years is changed. KURRE also compares the date of measurement with the date of paving to get correct predictions.

KURRE is the source of condition data for HIPS and PMS91. It produces also valuable reports to be used in evaluating the productivity of the maintenance or in planning of a reconstruction project. It lists the road sections with worst condition state, the condition history of an individual road segment etc. KURRE has also a map-interface to produce the information in a more illustrative form.

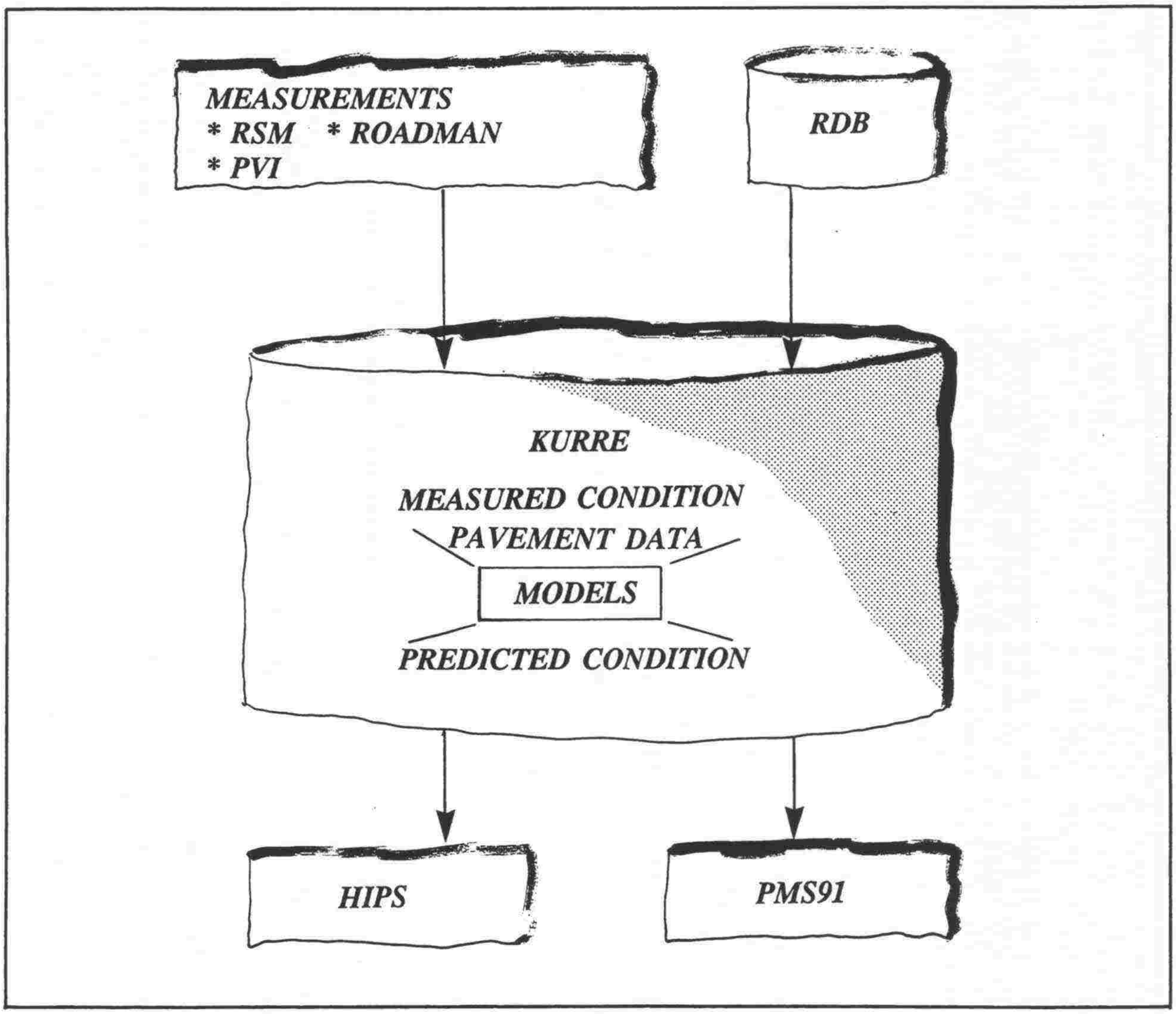


Figure 15. KURRE as part of PMS.

HIPS

HIPS retrieves conditon data from KURRE. It classifies ruts, evenness, defecets and bearing capacity into four classes and forms a condition state distribution matrice for the whole network. Then HIPS predicts the change in the distribution. The prediction depends on the volume class of the traffic and on which region of the country is in question. The prediction is made by using transition probabilities according to Markov process.

In long term optimization HIPS finds the condition state distribution minimizing the social cost: the sum of agency and user costs. It is possible to carry out the optimization using different frames. They help to estimate how a change in one variable would affect on some other variable: limit --> condition state, condition state --> budget level, action level --> total costs.

Short term optimization finds the means of improving the present condition state towards the optimum one. It gives within budget frame the time and the amount of different action levels needed for meeting the long term goal.

HIPS is used in strategic planning of the maintenance of the whole network. PMS91 uses the result of the short term optimization as input data when producing homogeneous road segments.

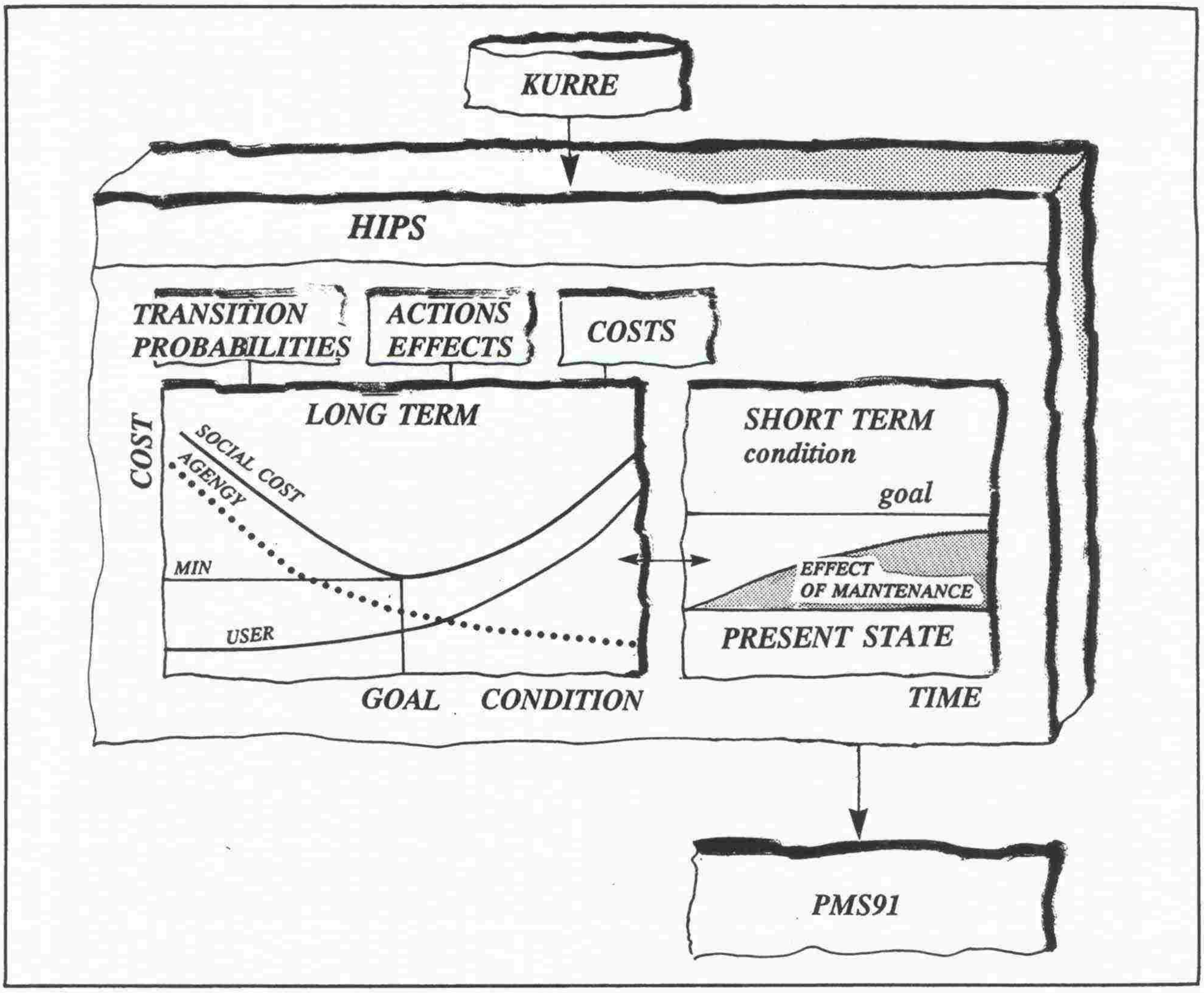


Figure 16. HIPS as part of PMS.

PMS91

PMS91 retrieves input data from RDB, KURRE and HIPS. The input data is mainly in hundred meter sections. Therefore there is a procedure for producing homogeneous road segments according to the condition state. The procedure is based on certain combination rules which take into account the action and timing recommended by HIPS.

The user gives threshold values for individual condition state indicators and defines decision rules for different rehabilitation actions. PMS91 predicts the change of the condition state segment by segment, year by year and compares the predicted condition state with threshold values. When a given threshold value is exceeded it recommends an action matching a decision rule.

PMS91 supports the interactive formation of maintenance projects and the adjusting of these projects to the resources available. The user produces the annual paving program with PMS91 and is also able to see rehabilitation need for a longer period. PMS91 gives tools for examining the effects of different actions and timings and evaluating how the planning meets the preset goals.

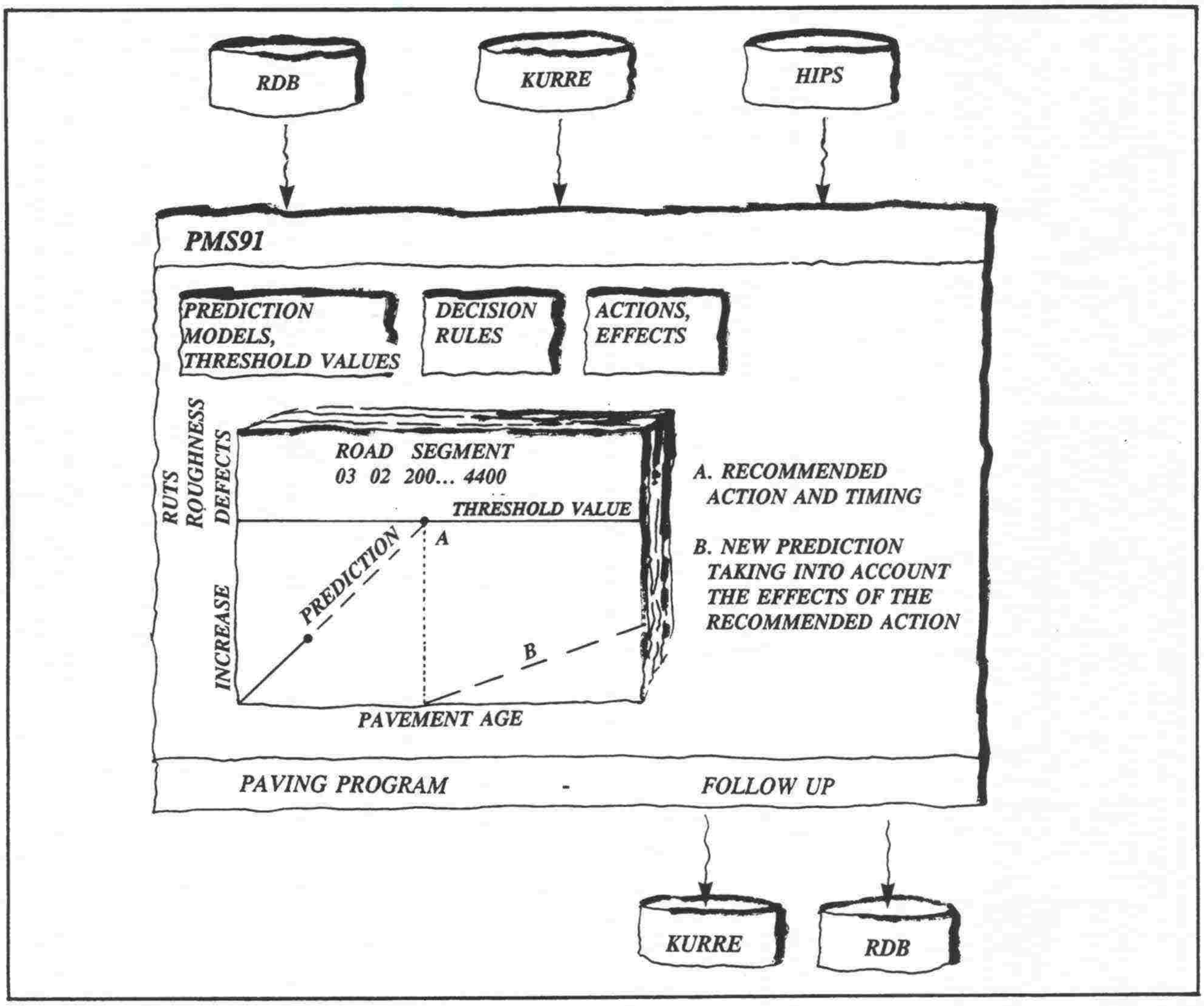


Figure 17. PMS91 as part of PMS.

III USING PMS IN THE PLANNING OF MAINTENANCE

Setting Goals

The goals of the maintenance are expressed in numerical values of rut depth, evenness and sum of defects for different road classes. These values are based on the current and optimal condition state and the known budget frame.

The Central Administration sets the goals for the following year by giving the maximum length of the road network which may exceed the given condition values. The annual goals are set to meet the long term optimization.

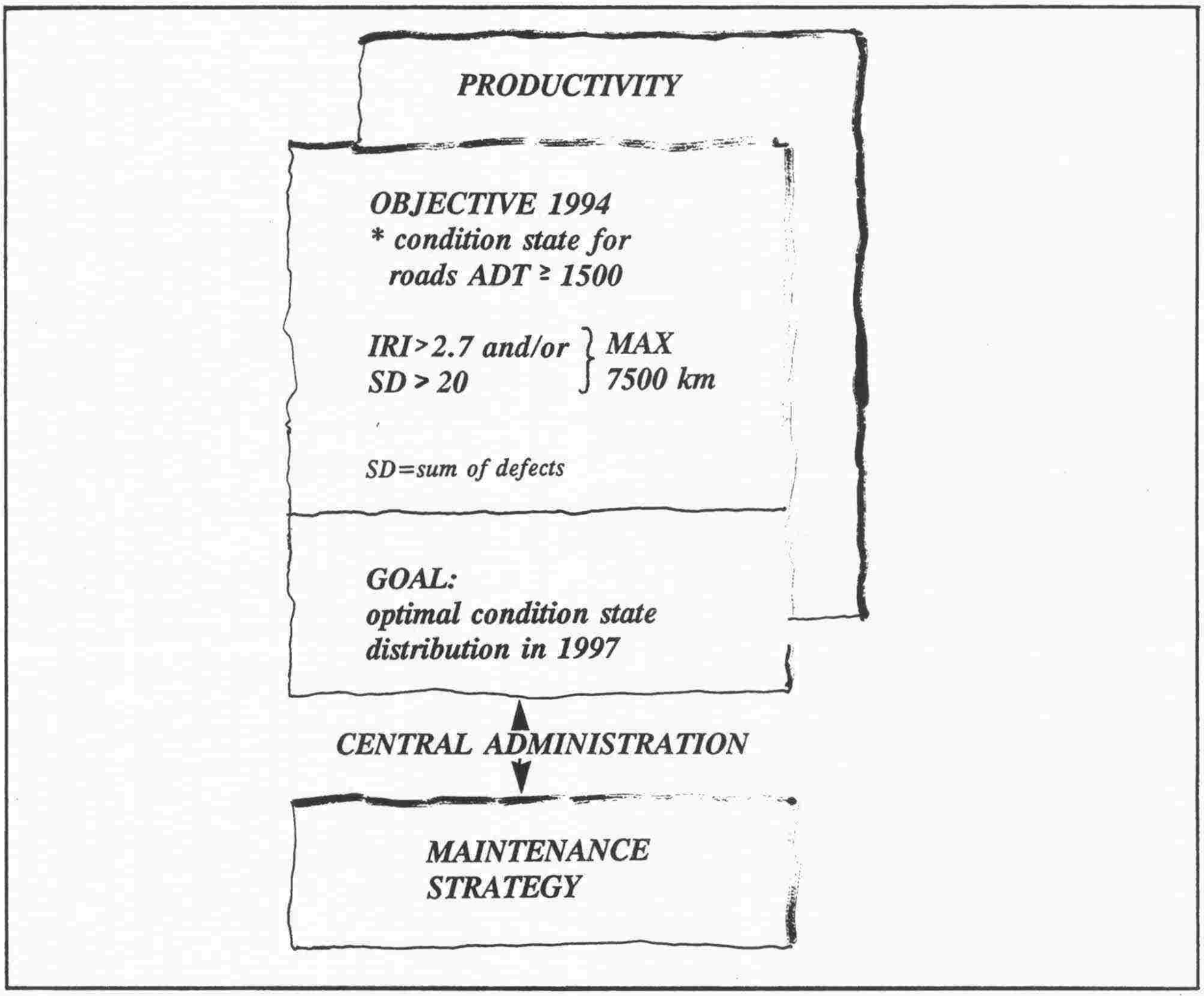
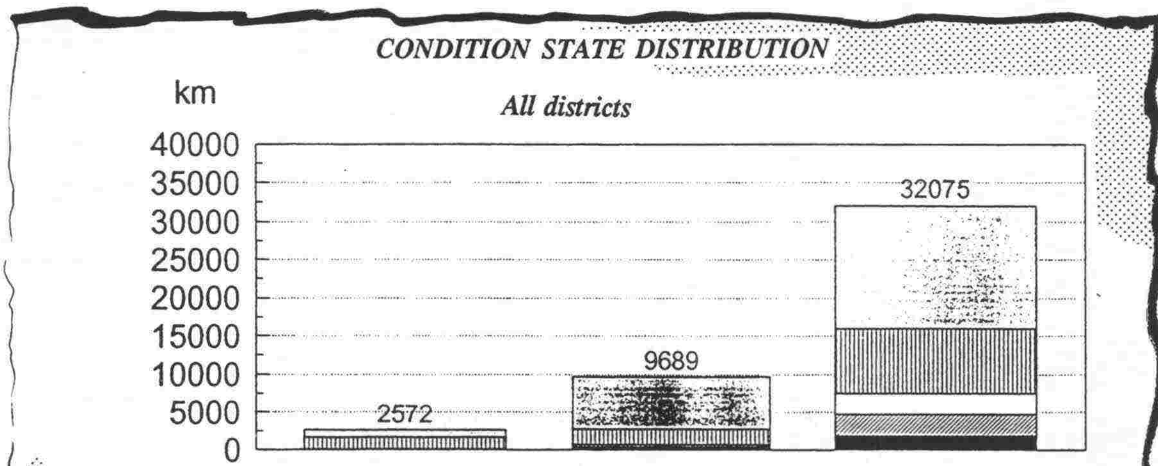


Figure 18. Goal setting in the Central Administration.

KURRE and HIPS are the tools for setting of these values. KURRE gives the present condition state distribution (figure 19) and HIPS finds the distribution of different actions to improve the condition state towards the optimal state within budget limits (figure 20).



km	ADT > 6000	ADT 1500 - 6000	ADT < 1500
IRI>3,5 and SD>30/60	1	75	1884
SD>30/60	8	298	2850
IRI>3,5	40	280	2775
Not measured	1506	2074	8444
Good condition	1017	6962	16122

Figure 19. Condition state distributions: present state.

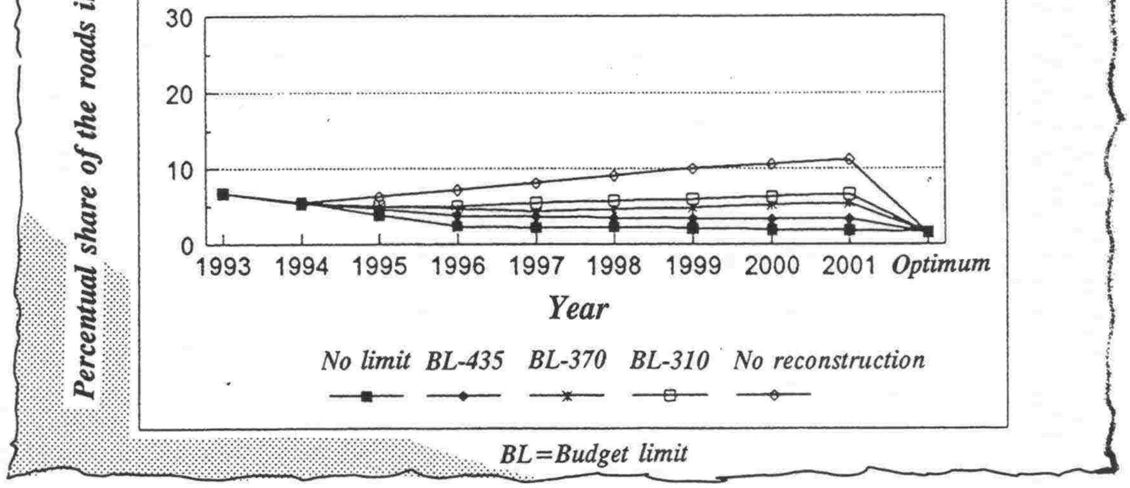


Figure 20. Analyzation of the effect of the budget limits. (HIPS)

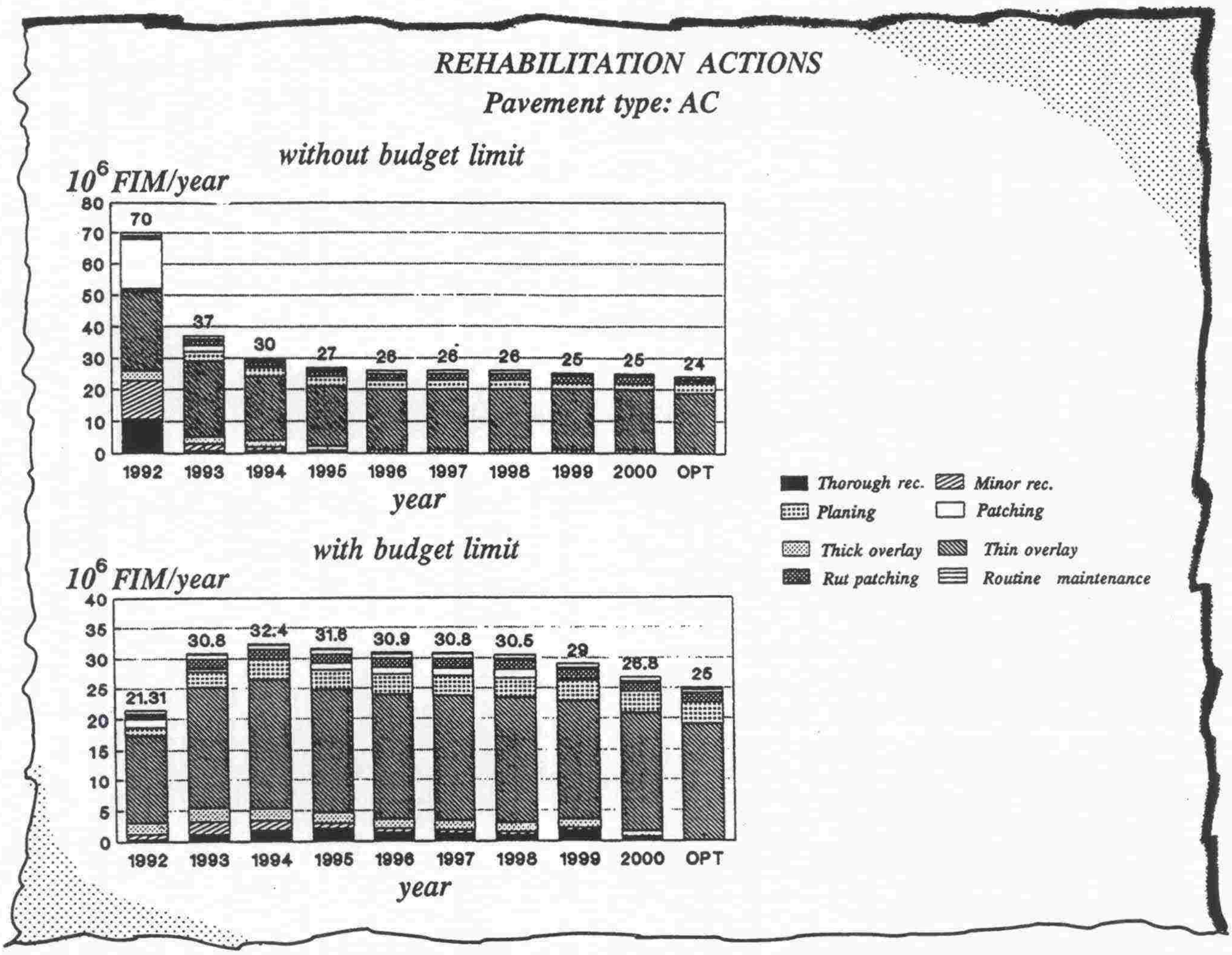


Figure 21. Recommended actions, HIPS.

The district offices set their goals and measures of productivity within the given limits. Then they produce the detailed program of repaving for the following year and also the general plan for maintenance actions for the following 4 years.

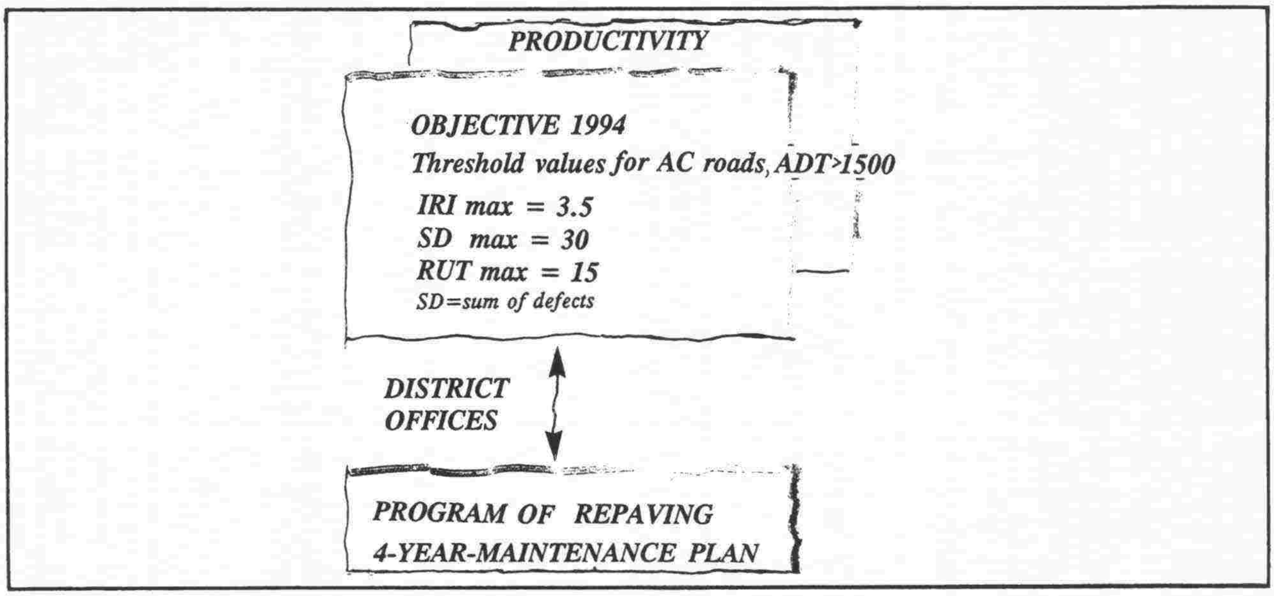
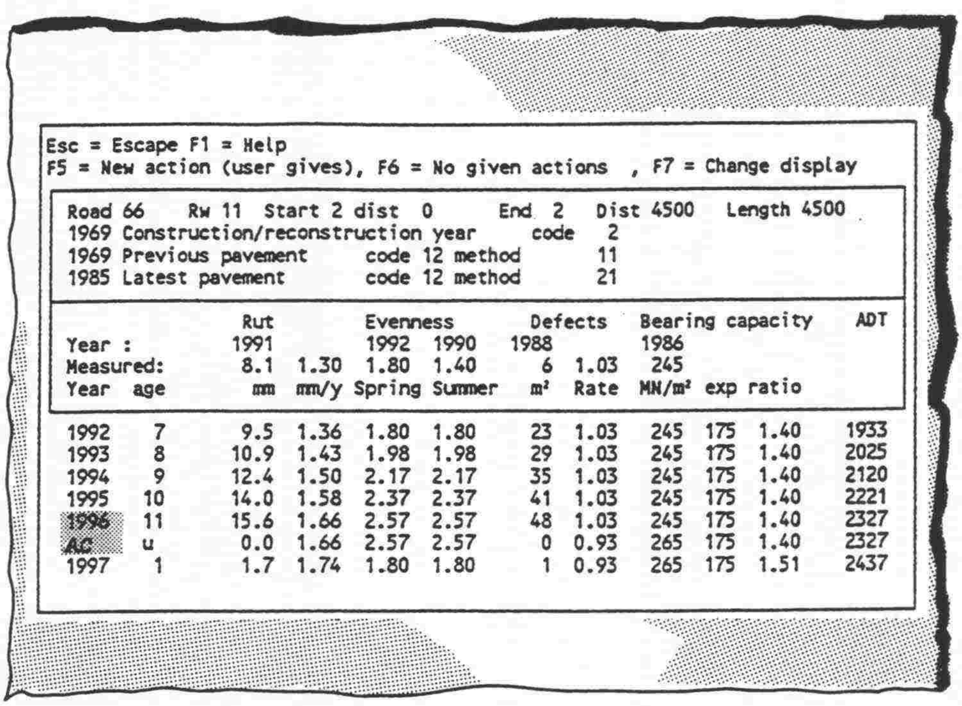


Figure 22. Goal setting in the district offices.

Meeting Goals

PMS91 is used for finding the best action and timing for a certain road segment (figure 23). The paving programme is planned with PMS91 and the actual repaving work is followed up by using PMS91.



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Esc = Escape F1 = Help
F5 = New action (user gives), F6 = No given actions  , F7 = Change display

 Road 66    Rw 11  Start 2 dist  0      End  2   Dist 4500   Length 4500
 1969 Construction/reconstruction year     code   2
 1969 Previous pavement      code 12 method       11
 1985 Latest pavement        code 12 method       21

                   Rut          Evenness      Defects    Bearing capacity     ADT
 Year :            1991         1992  1990   1988        1986
 Measured:          8.1  1.30   1.80  1.40      6  1.03   245
 Year   age          mm  mm/y Spring Summer    m²  Rate MN/m² exp ratio

 1992    7          9.5  1.36   1.80  1.80     23  1.03   245  175  1.40     1933
 1993    8         10.9  1.43   1.98  1.98     29  1.03   245  175  1.40     2025
 1994    9         12.4  1.50   2.17  2.17     35  1.03   245  175  1.40     2120
 1995   10         14.0  1.58   2.37  2.37     41  1.03   245  175  1.40     2221
 1996   11         15.6  1.66   2.57  2.57     48  1.03   245  175  1.40     2327
 AC      u          0.0  1.66   2.57  2.57      0  0.93   265  175  1.40     2327
 1997    1          1.7  1.74   1.80  1.80      1  0.93   265  175  1.51     2437
```

1996 action and/or timing
AC may be changed

Figure 23. Evaluating the effect of changing action and/or timing. (PMS91)

KURRE gives valuable information about the condition history of different road segments to analyze the effects of previous maintenance actions (figure 24). It makes lists and maps of different condition data: the worst road segments, a summary of the road length exceeding the given values. While planning the detailed actions for a certain road segment the user may for example use rut profiles to help to make the decisions (figure 25).

CONDITION STATE HISTORY

Subroad/Distance

Road 53 3/0 - 3/2400

Average	*87*	*88*	*89*	*90*	*91*	*92*	*87-9~~1~~2*
IRI	*1.1*	*1.1*	*1.5*	*1.9*	*2.0*	*2.7*	
RUT	*1*	*1*	*1*	*2*	*8*	*10*	
SD	*2*	*2*	*10*	*15*	*16*	*20*	
INCREACE PER YEAR							
IRI	--	--	*0.4*	*0.4*	*0.1*	*0.7*	*1.6*
RUT	--	--	--	*1*	*6*	*2*	*9*
SD	--	--	*8*	*5*	*1*	*4*	*18*

ADT

3/0 - 3/100	*3524*
3/100 - 3/300	*3000*
3/300 - 3/2400	*2000*

SPEED LIMIT

3/0 - 3/200	*80 km/h*
3/200 - 3/400	*100 km/h*
3/400 - 3/2400	*80 km/h*

Figure 24. Condition state history: for evaluating if the maintenance policy has been suitable.

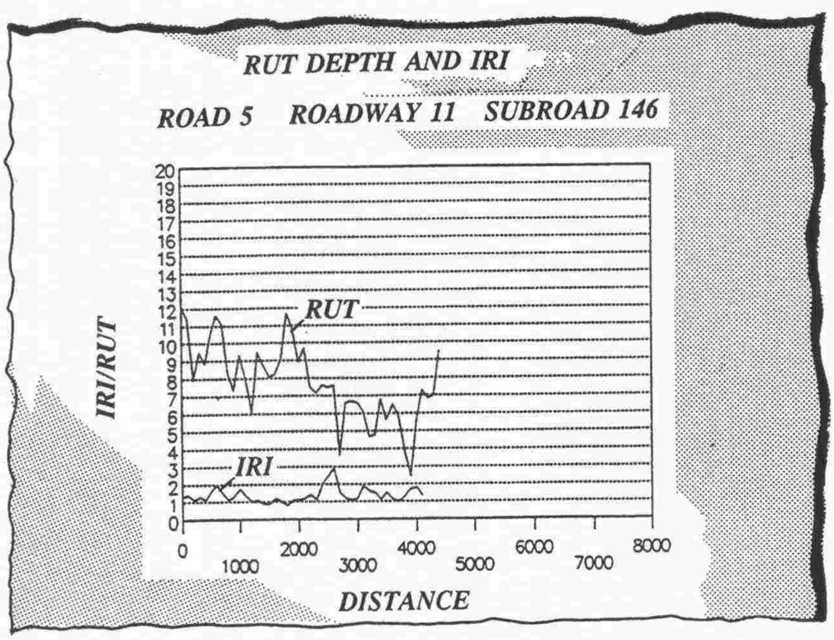


Figure 25. Profiles for adjusting right actions.

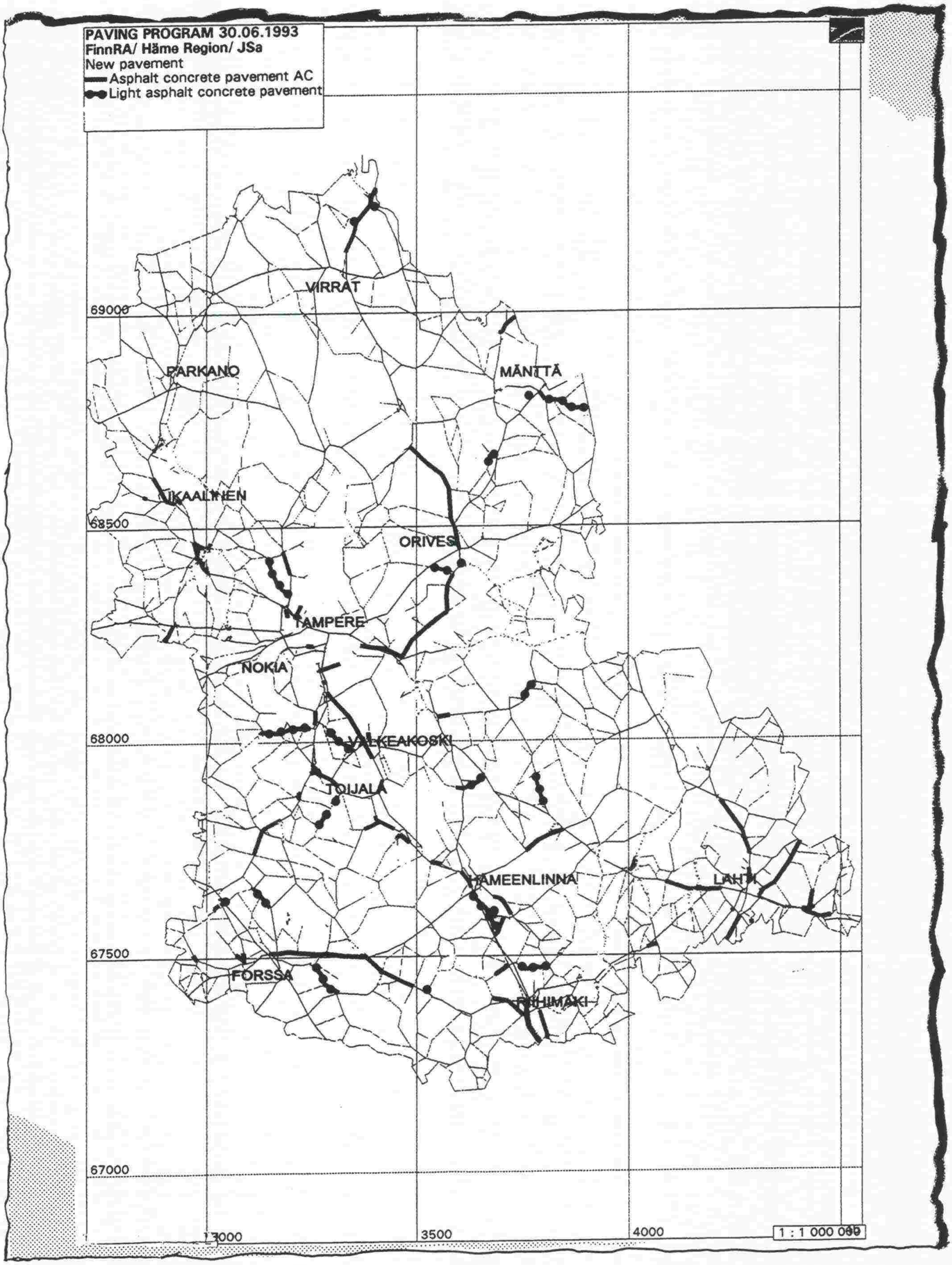
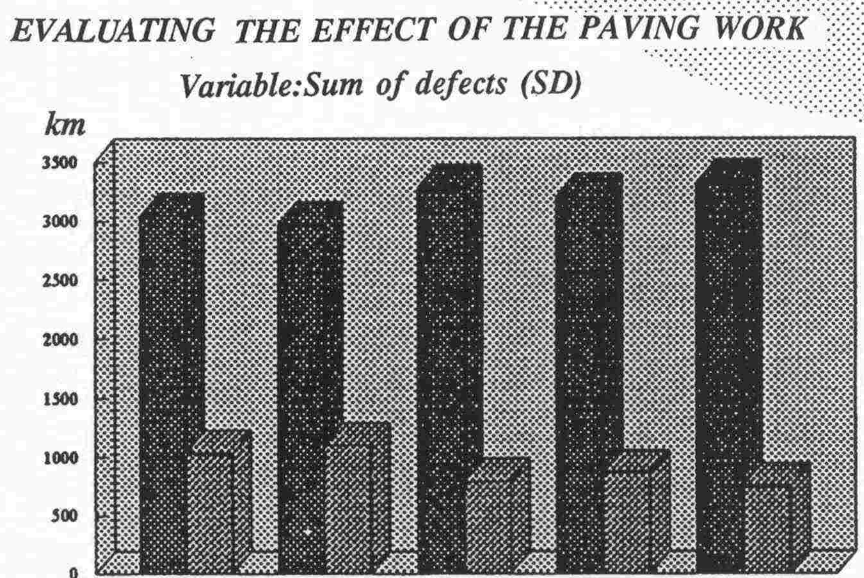


Figure 26. Program of repaving work. (PMS91)

After the program is made the effects and also the productivity are evaluated by using both PMS91 and KURRE.



	1992 Autumn	1993 Spring	1993 Autumn	1994 Spring	1994 Autumn
SD < 60	3039	2970	3280	3202	3316
SD > 60	1029	1098	788	866	732

SD< 60 = acceptable condition
SD> 60 = unacceptable condition

Figure 27. Evaluating the effect of the paving program. (PMS91)

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AVERAGE IRI

Pavement type: AC

Threshold value > 3.5

Maintenance class	I km(%)	II km(%)	III km(%)	IV km(%)	V km(%)
not measured	16(36)	9(5)	6(2)	18(9)	6(58)
new pavement	6(22)	77(42)	122(33)	27(13)	-(-)
threshold value					
* not exceeded	6(21)	92(50)	223(60)	125(62)	2(23)
* exceeded	0(1)	5(3)	18(5)	31(15)	2(19)

Figure 28. Measuring the productivity of maintenance work. (KURRE)

Benefits

Along with the development and use of PMS a great amount of exact condition data is now available for different management and planning tasks. The prediction models and the evaluation of the effects of different maintenance actions are getting more accurate and therefore also the optimization is getting more value.

PMS is an objective tool to set the goals for strategic planning and measurements of productivity. It has increased the cost/benefit - awareness of the maintenance staff and along with that effectivity and cost effectiveness has increased.

PMS makes possible to forecast different situations and adjust recources to needs. It makes the lack of money to cause harm as little as possible.

TIELAITOKSEN SELVITYKSIÄ

29/1993 Tieinvestointien toteutustapa viidessä Euroopan maassa. TIEL 3200155

30/1993 Pasilan virastokeskuksen työmatka- ja työliikennetutkimus. TIEL 3200156

31/1993 Savo-Karjalan tiepiirin murskaustoiminnan kehittäminen.

32/1993 Tiemerkintöjen näkyvyys; Paluuheijastavuustutkimus Lapin tiepiirissä. TIEL 3200157

33/1993 Tiesuolan pohjavesivaikutusten mallintaminen Joutsenonkankaalla. TIEL 3200158

34/1993 Kalliomurskeiden tiivistyminen ja hienoneminen, esitutkimus. TIEL 3200159

35/1993 Strategic Highway Research Program (SHRP) - Longterm Pavement Performance (LTPP); Koeteillä tehdyt mittaukset vuonna 1992 ja tierakenteen vaurioitumiseen vaikuttavat tekijät. TIEL 3200160

36/1993 Palaturpeen käyttö lämpöeristeenä, raportti koerakenteiden rakentamisesta TIEL 3200161

37/1993 Talvikunnossapidon laadun logistiset vaikutukset. TIEL 3200162

38/1993 Sitomattomien kerrosten kiviainesten muodonmuutosominaisuudet; Kirjallisuusselvitys. TIEL 3200163

39/1993 Sitomattomien kerrosten kiviainesten muodonmuutosominaisuudet; Esiselvitysvaiheen kuormituskokeet. TIEL 3200164

40/1993 Teiden tasaisuusmittareiden vertailu; PTM:n, Roadmanin ja Dipstickin laitevertailu sekä epätasaisuuksien vaikutus tierasitukseen. TIEL 3200165

41/1993 Stabiloidun materiaalin maksimiraekoon sekä koekappaleen koon ja muodon vaikutus puristuslujuuteen. TIEL 3200166

42/1993 Tieliikennemelun mittaaminen; Opas. TIEL 3200167

43/1993 Asfaltti- ja murskausasemien melun leviäminen. TIEL 3200168

44/1993 Auton polttoaineenkulutuksen joustot eri väestöryhmissä; esitutkimus. TIEL 3200169.

45/1993 Talvirengastutkimus; Talvirenkaiden käyttö ja kunto sekä kuljettajien arviot talvirenkaistaan talvikaudella 1992-93. TIEL 3200170

46/1993 Tieympäristön pehmentämisen turvallisuusvaikutukset. TIEL 3200171

47/1993 Väsymissuorat tierakenteen mitoitusta varten. TIEL 3200172

48/1993 Tietullit ja käyttömaksut; Asennoituminen tie- ja automaksuihin. TIEL 3200173

49/1993 Tiesuolaus ja pohjavedet; nykytilan selvitys. TIEL 3200174

50/1993 Ympäristöpainotteinen taajamatie Ylistarossa; Yleissuunnittelun arviointi. TIEL 3200175

51/1993 Liikenteen informaatiopalveluiden käyttötutkimus. TIEL 3200176

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